Open Geometry HTS MRI System

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Help

Summary

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NREL

Project Wrap-up

- This project was ended for business reasons in July 2004 by mutual consent of Oxford Instruments (project leader) and Siemens (magnet/cryogenics/system integrator).
- Technically the project aim appears attainable, but the system economics do not warrant additional investment.
- A primary factor in this decision is the significant shift in the MRI market to higher field strengths since this project was proposed in 2000/2001.
- Although we have demonstrated relatively low cost 2212 conductor, a business assessment concluded that the likely return on investment does not warrant further development.
- This presentation will summarize the technical achievements of the project and the market shifts that led to the decision to stop work.

HTS MRI Team

- OST: project leader and conductor fabrication
- SCI Engineered Materials: precursor powder optimization and synthesis
- Siemens Magnet Technology (formerly OMT): HTS MRI magnet and cryogenics
- Siemens Medical Solutions: system integration and imaging trials
- LANL: precursor powder research and conductor characterization
- NREL: higher performance conductor research

Cost Effective Conductor

- Note that the overriding issue for this project is really economics: can the system be made at a competitive cost.
- The MRI coil and system technology was previously demonstrated with BSCCO-2223, but conductor costs were much too high.
- So the real target is a *cost effective conductor,* that is minimizing conductor $/kA-m.
- This includes issues of starting materials, fabrication technology, and performance optimization.
- There are additional issues for HTS coil development and optimization, since this conductor configuration is quite different from previously used superconductors.

FY 2004 Objectives

- ✓ March 2004: Powder processing upgrades complete and qualified by conductor performance.
- ✓ March 2004: Reduced cost powder precursors in use.
- ✓ o July 2004: Prototype conductor processing line completed and the process qualified by test coil results.
- December 2004: Conductor fabrication complete (20 – 25% complete by Oct 1, 2004)
- September 2004: Cryogenics and magnet designs complete.

Superconductor Powder Optimization

Fiscal Year 2004 Objectives

- Complete Precipitation System Automation (Q1)
- Complete Filtration System Implementation (Q1)
- Complete Calcination System Optimization (Q2)
- Implement Low Cost Raw Materials (Q1)
- Qualify Complete System (Q2)

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Superconductor Powder Optimization

Fiscal Year 2004 Results

- Automated Precipitation Installation Complete
  - 10kg lot prepared and qualified by OST
  - System installed in new SCI facilities
  - Prepared to supply powder for tape conductor fabrication

- Filtration System Installed and Qualified
- Calcination System Optimization Complete
  - 10kg lot processed and qualified by OST
- Complete System Qualified and Ready for Production

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Superconductor Powder Optimization

Fiscal Year 2004 Results

- Implementation of Low Cost Materials
  - Use of Low Cost Nitrate Solution Materials Qualified by OST
  - Will be used to Prepare Conductor Powder for Tape Fabrication
- Total Cost Reduction Potential of 60 - 70%
  - Based on Large Lot Size (>1000kg per year) Production

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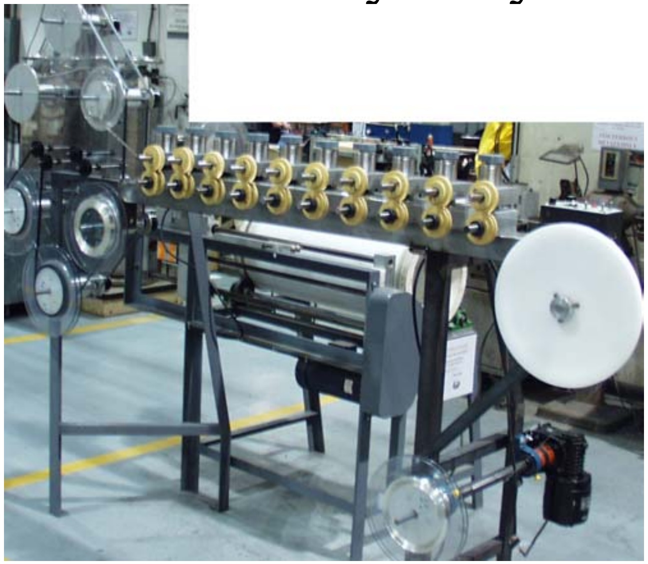
FY 2004 Results: Conductor

Conductor Summary

- Prototype processing line completed.
- Conductor performance verified in short samples and in 10 m test lengths.
- 2 km length capability, present 500 m limited by alloy substrate supply.

Coating



Sheathing

Melt Processing

Final Tape

National Laboratory Support of the Open Geometry MRI Superconductivity Partnership Initiative

Terry Holesinger

Los Alamos National Laboratory

Contributors and Outline

- Los Alamos National Laboratory (LANL)
  - Terry Holesinger, Jeff Willis, Yates Coulter, and John Kennison
- National Renewable Energy Laboratory (NREL)
  - Raghu Bhattacharya, Priscila Spagnol, Tapas Chaudhuri, Sovannary Phok
- Purpose - to provide unique expertise and capabilities that exist at the National Laboratories to our industrial partners in support of the Open Geometry MRI Superconductivity Partnership Initiative.
- Outline
  - LANL contribution in powder synthesis, microscopy, and electrical characterization.
  - NREL contribution in nanoparticle additions for improving flux pinning.

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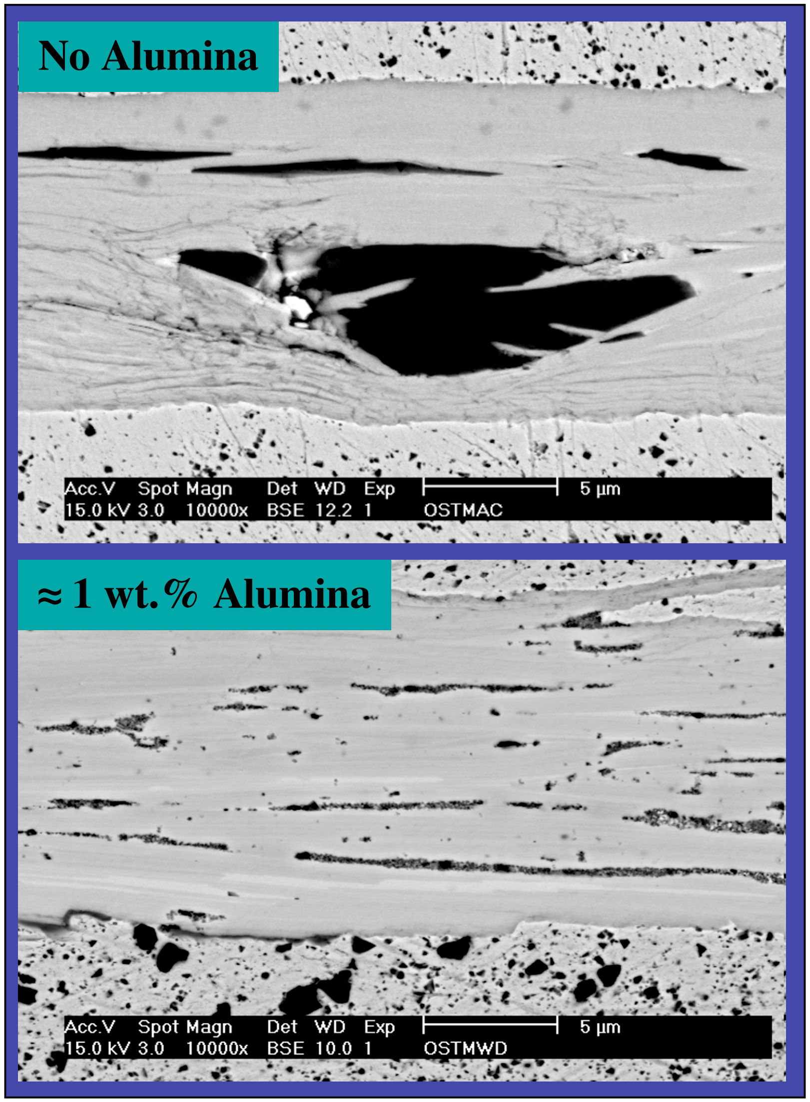
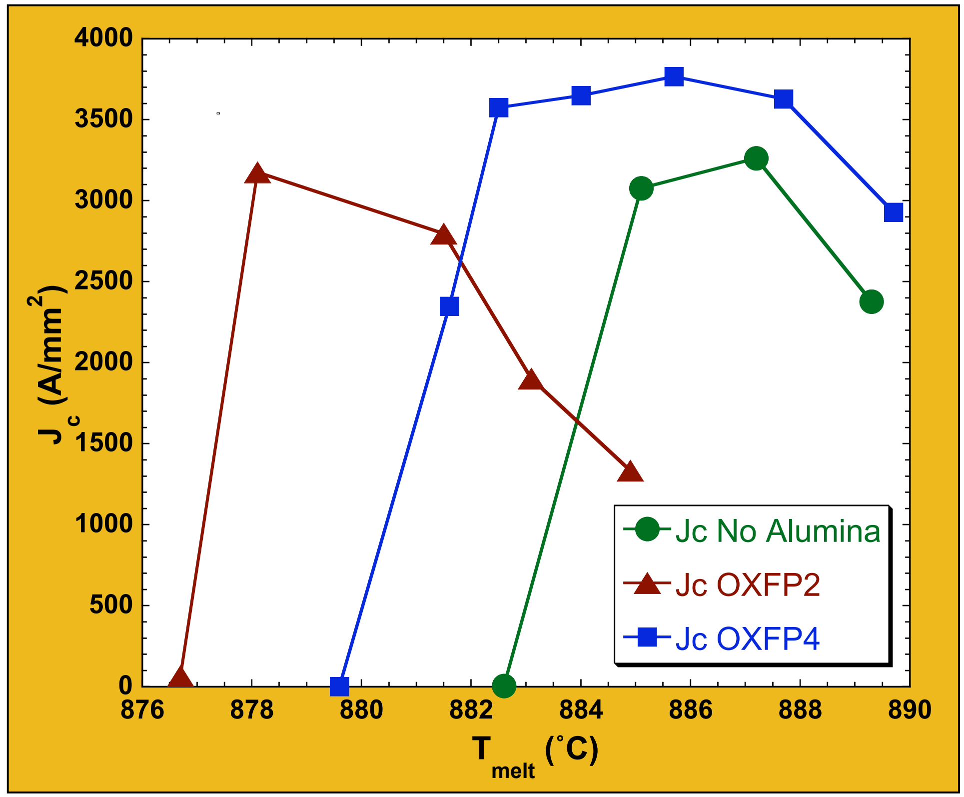
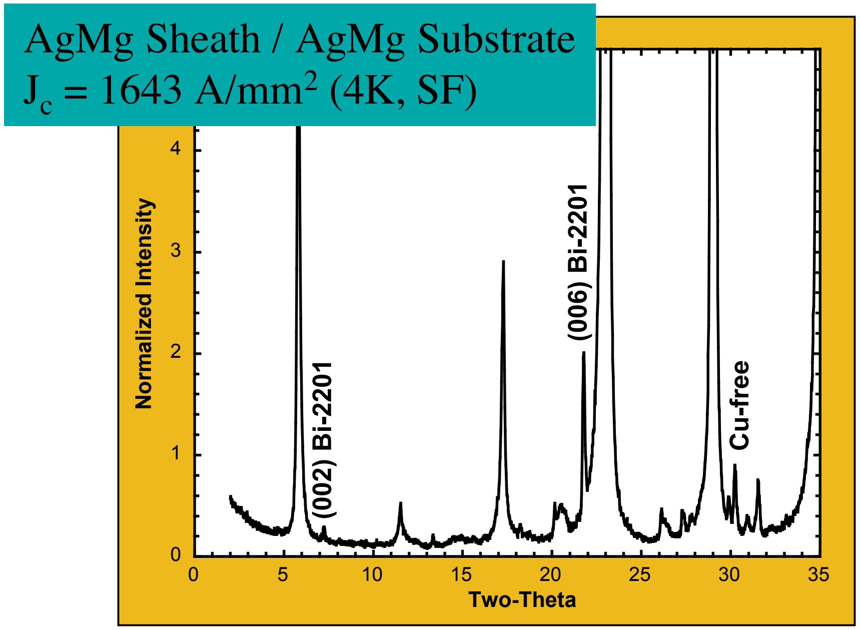
Alumina additions to starting powder is a viable approach for refinement of secondary phases in Bi-2212 tapes.

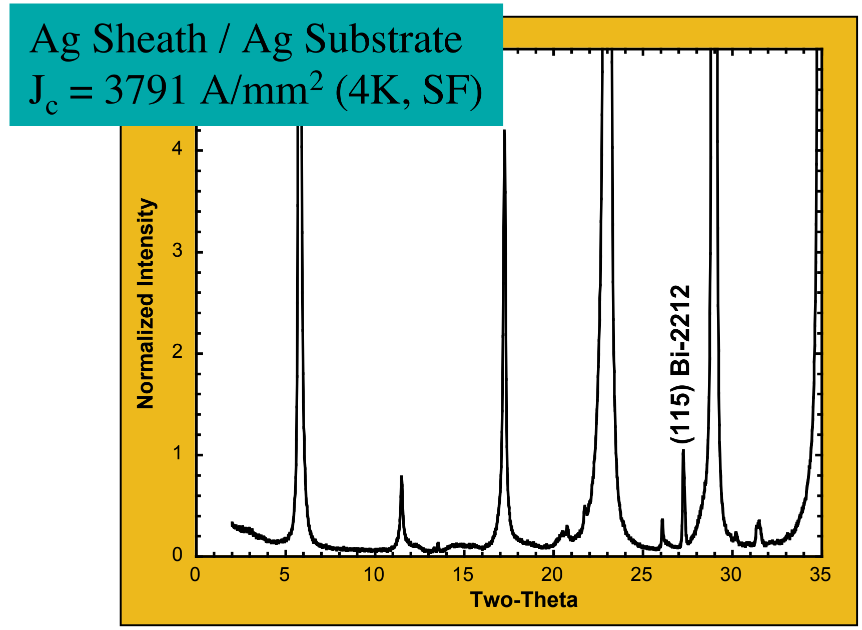


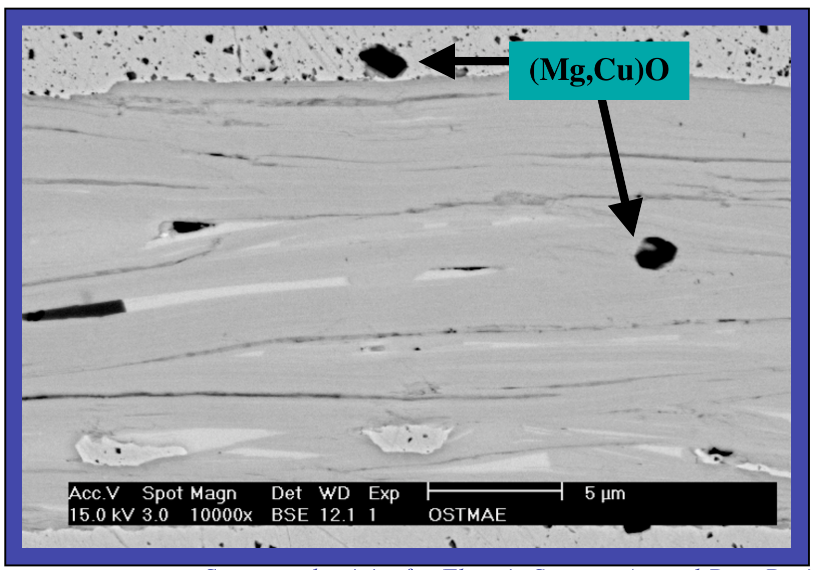
- Large secondary phases can disrupt the local alignment of the superconducting phase.
- Alumina additions result in smaller secondary phases and improved performance.



The formation of (Mg,Cu)O impurity phases in tapes with AgMg substrates / sheaths appears responsible for I_c degradations.



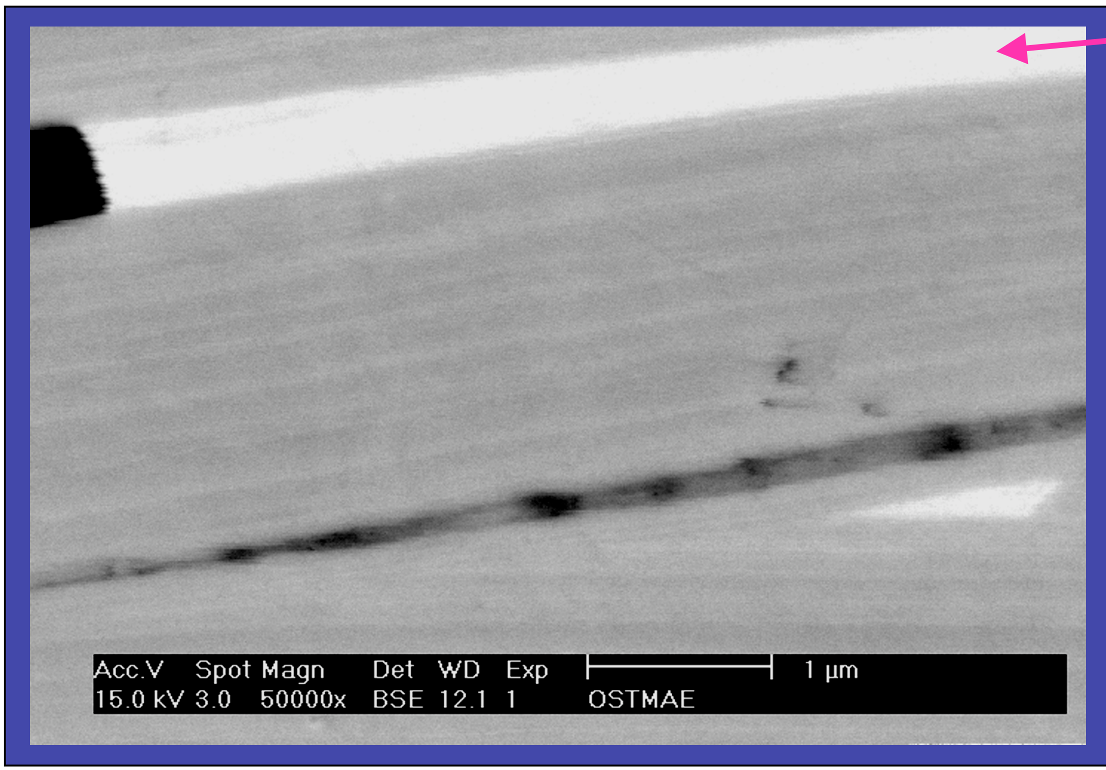




- (Mg,Cu)O (Cu ≈ 10-15 at.%) particles at the sheath interface and within filaments.
- Concurrent increase in Bi-2201 / Cu-free impurity phase content with particle formation.
- We believe that the problem can be fixed with CuO additions to starting powder (in progress).

Chemical analysis of the superconducting phase within fully processed tapes has helped refine starting powder compositions.

- All compositions of the Bi-2212 superconducting phase were Sr-rich, Ca-deficient relative to the ideal composition.
  - $Bi_{2.17}Sr_{2.02}Ca_{0.84}Cu_{1.97}O_y$
- The starting powders that are close to this measured composition have produced the highest J_c values in the Bi-2212 tapes.

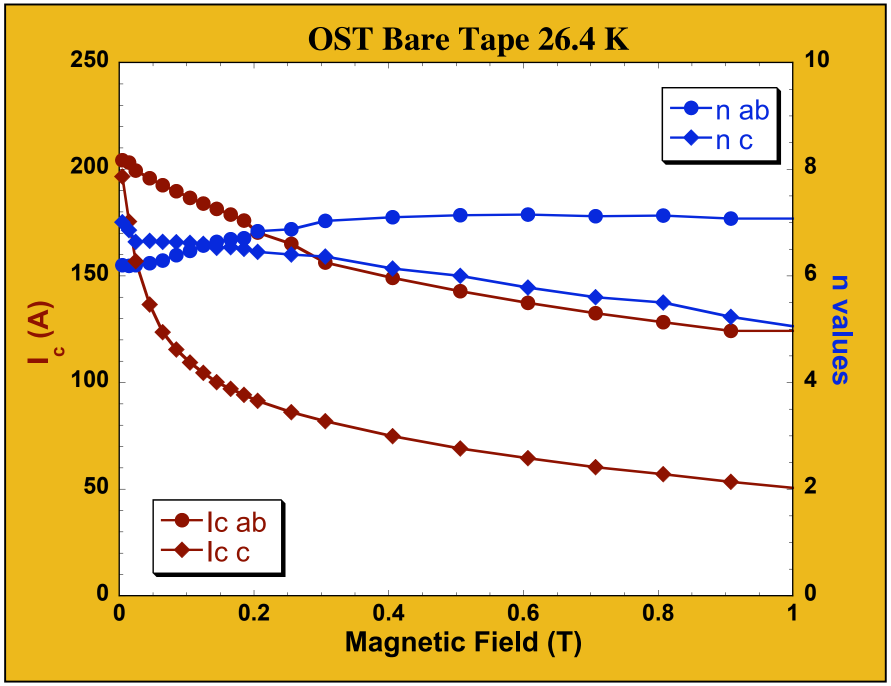


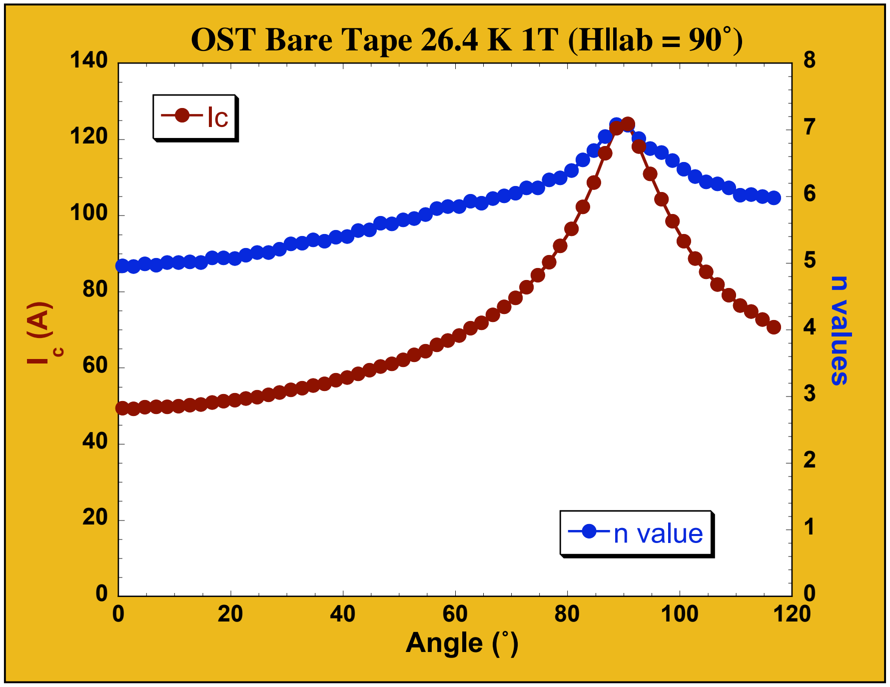
Bi-2201

Streaks within Bi-2212 grains indicate some additional structure within the Bi-2212 grains.

Transport measurements in Liquid Neon were used to gather the J_c data needed for coil simulations and design.

- Measured on 2 mm wide patterned tape, scaled to 1 cm wide, double sided tape
- I_c (26.4 K, sf) ~200 A, n ~ 7.2 and good in field performance

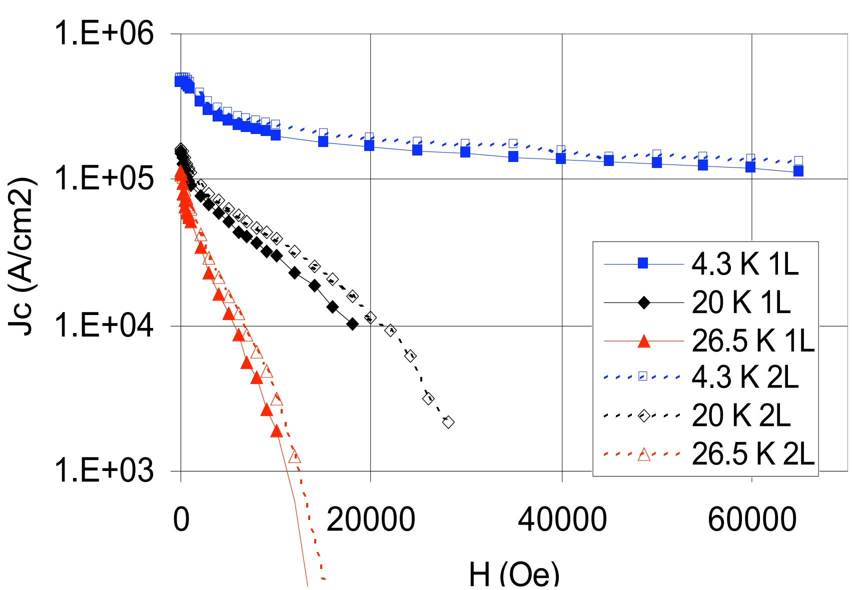




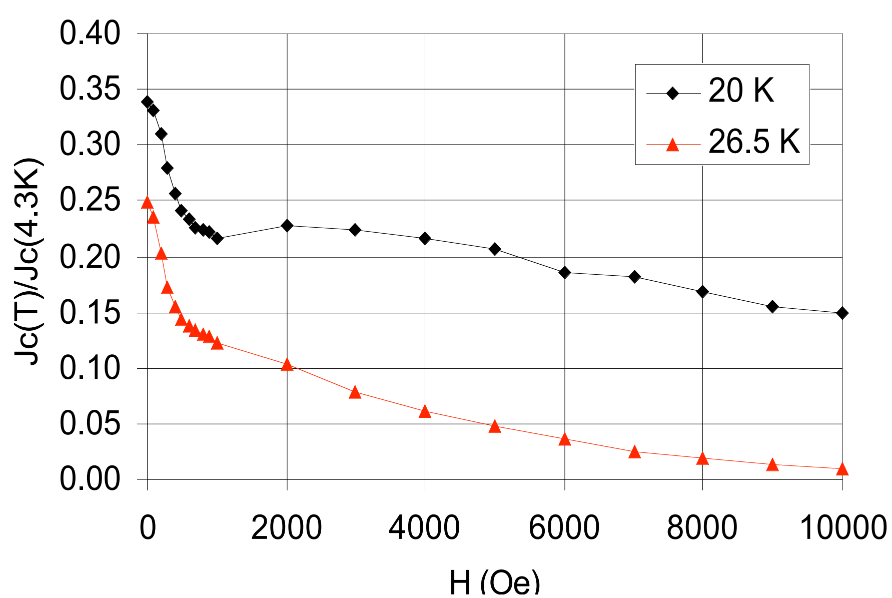
J_c measurements using a SQUID magnetometer and the Bean critical state model showed little J_c degradation with double layer tapes.

- Two layer tapes can be used for doubling the critical current of the conductor.
- Field and temperature dependence of one and two layer tapes are similar.
  - J_c(4.3K) ~ field independent; J_c(20K, 26.5K) decrease exponentially with H
  - J_c(20K) ~15-20% of J_c(4.3K); J_c(26.5K) from 12%(1 kOe) to 2%(10 kOe) of J_c(4.3K)

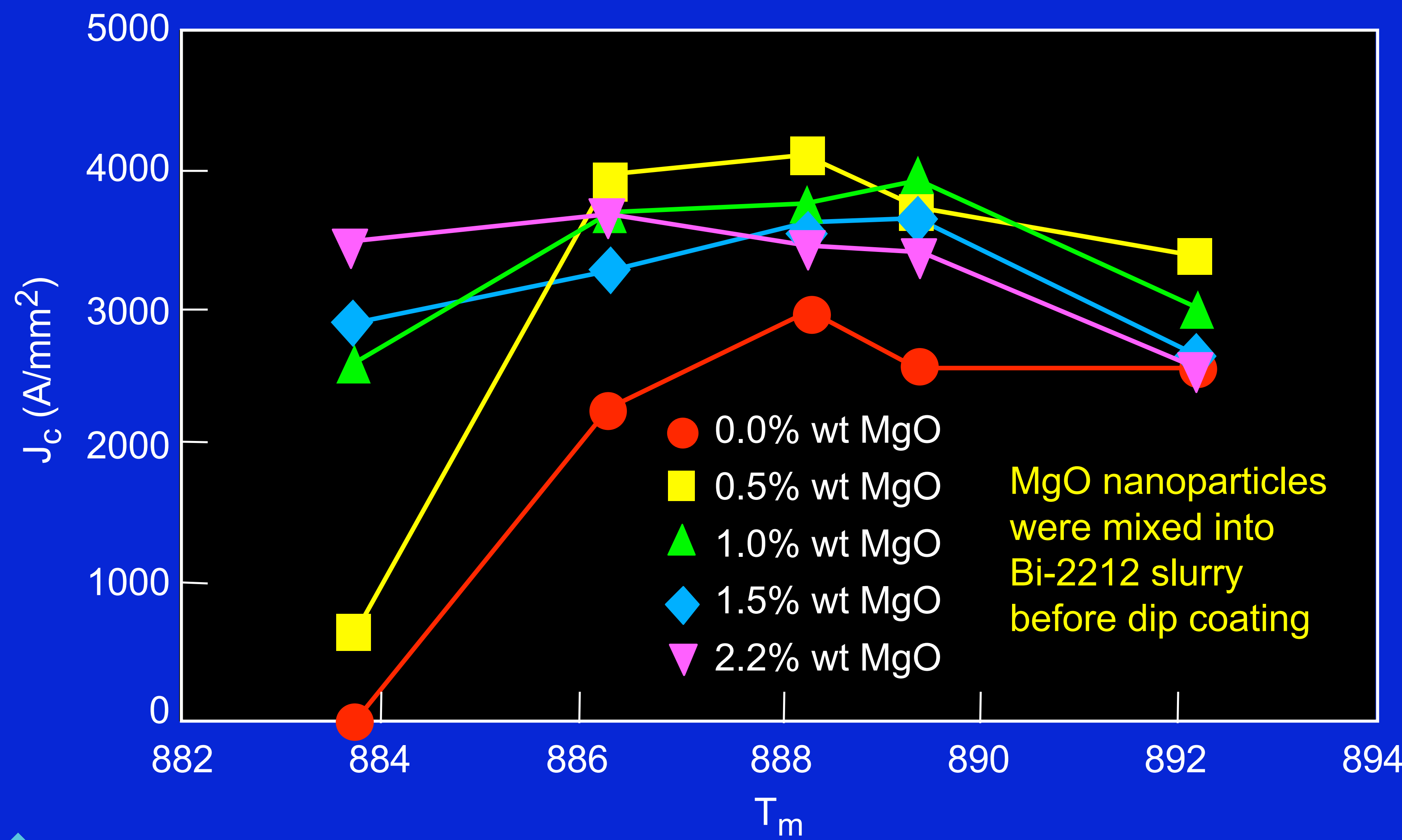
OST 1 Layer and 2 Layer Sheathed Tape
Magnetization Jc H//c



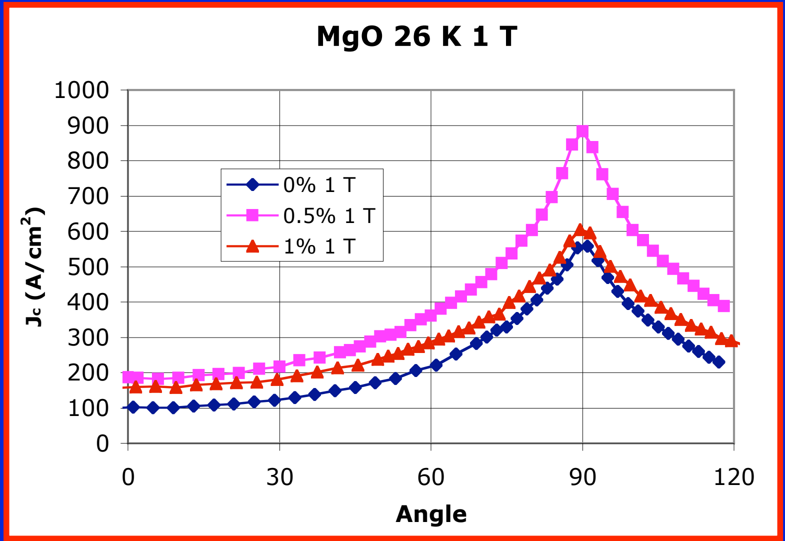
OST 1 Layer Sheathed Tape
Normalized Magnetization Jc(T) H//c

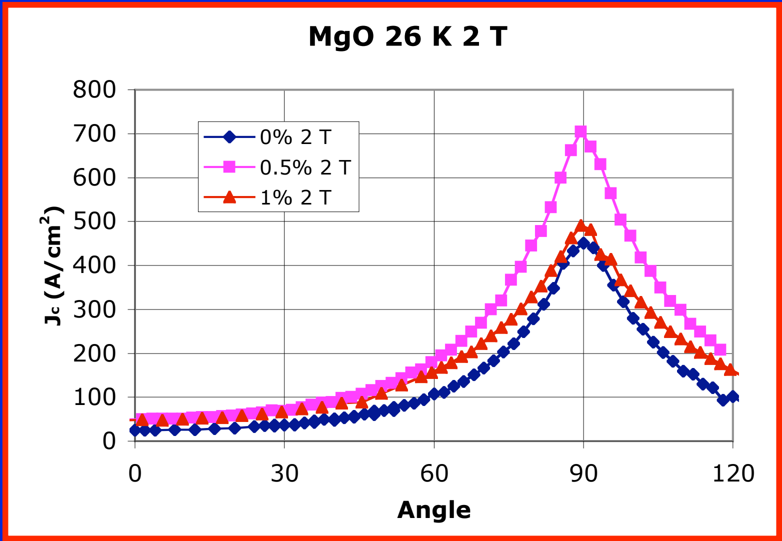


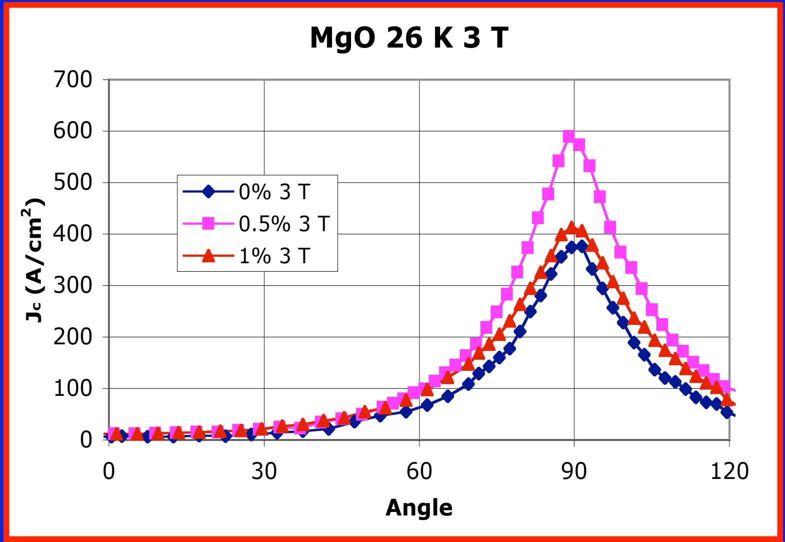
J_c levels were increased in short lengths for several levels of MgO nanoparticle additions



Angular Field Dependence of the Critical Currents shows best J_c Improvement for 0.5 wt% Additions

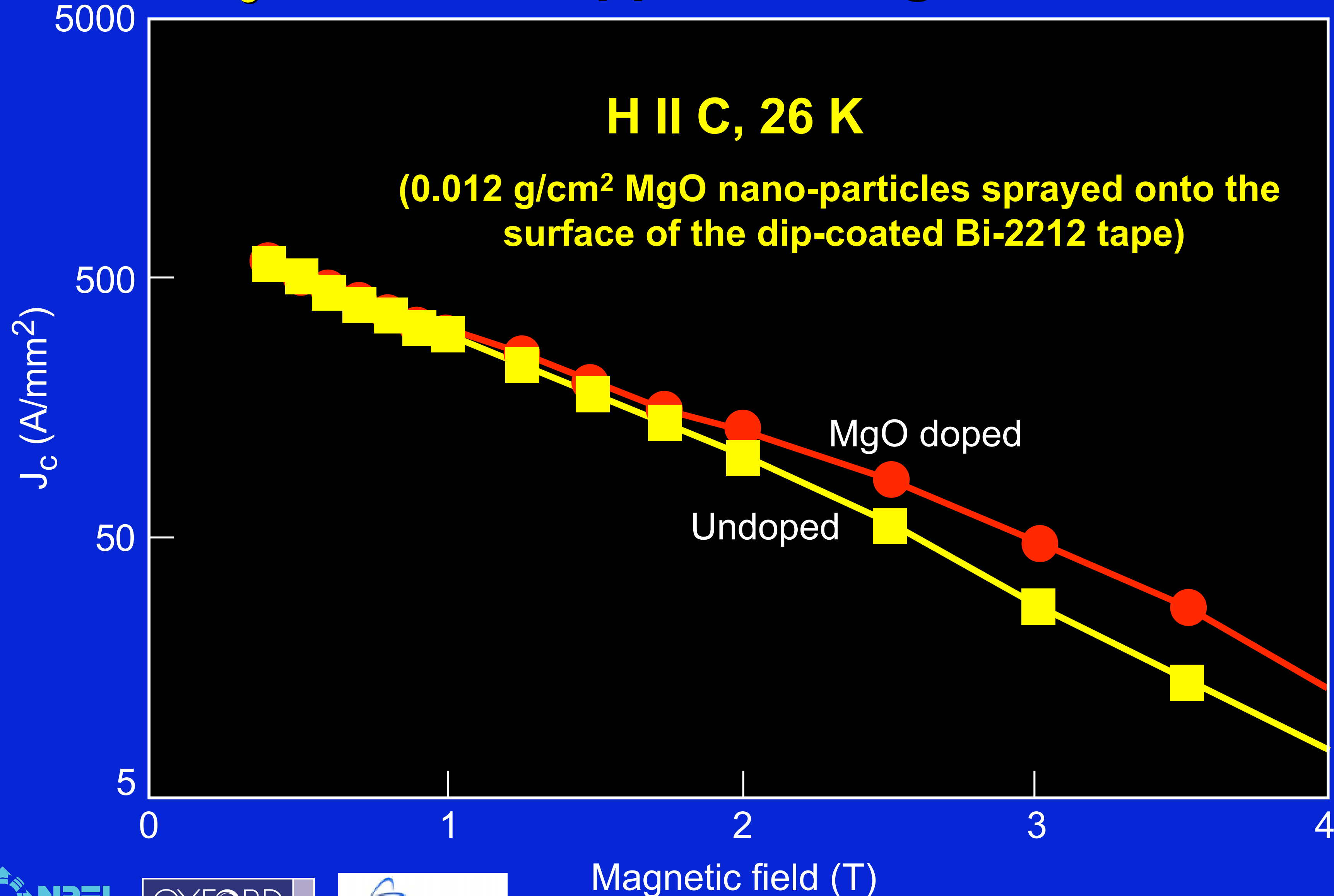




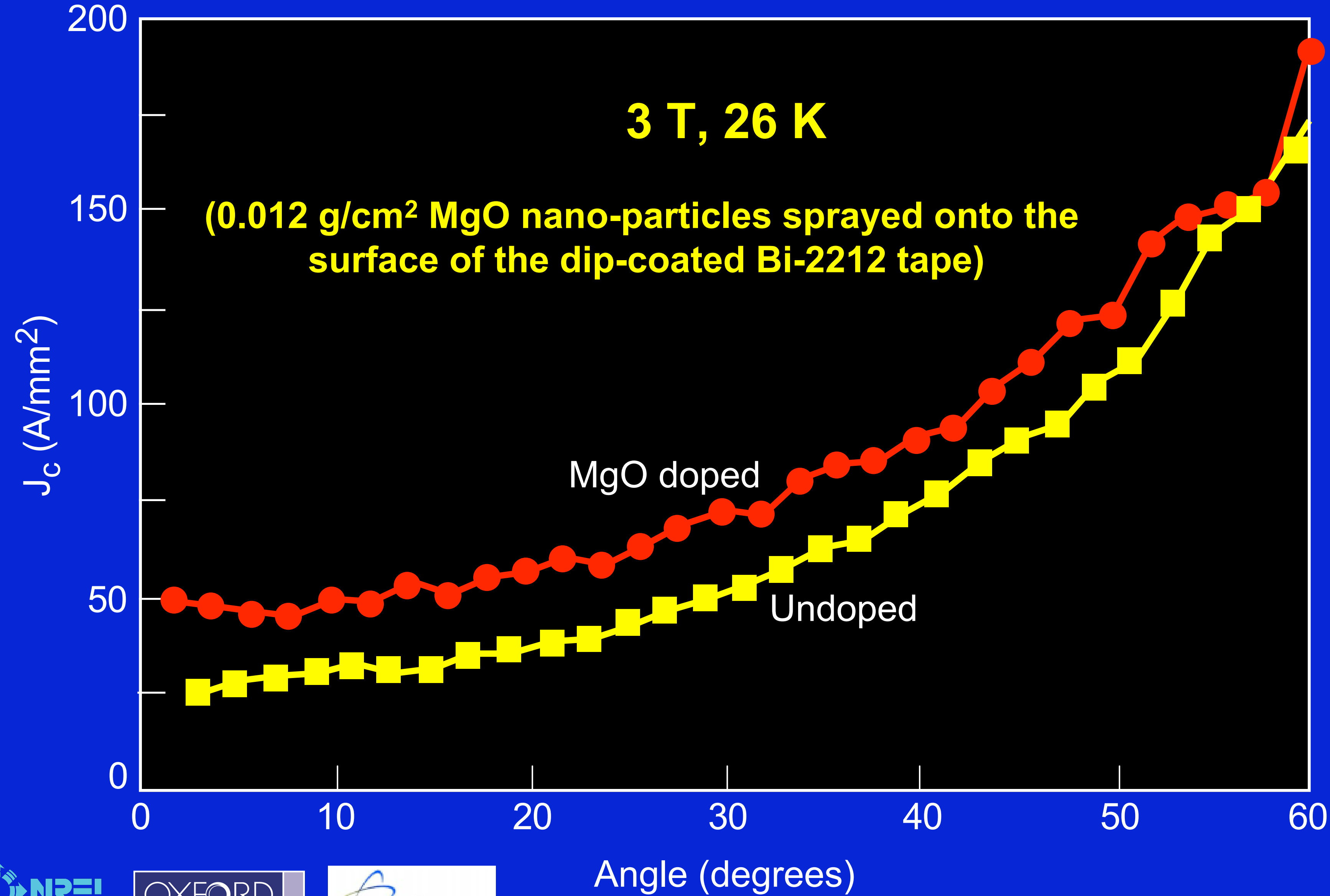


MgO nanoparticles were mixed into Bi-2212 slurry before dip coating

Angular Field Dependence Show an Improvement in J_c for Fields Applied along the c-axis



At 3 T, the J_c improvement for H||c is approximately a factor of two



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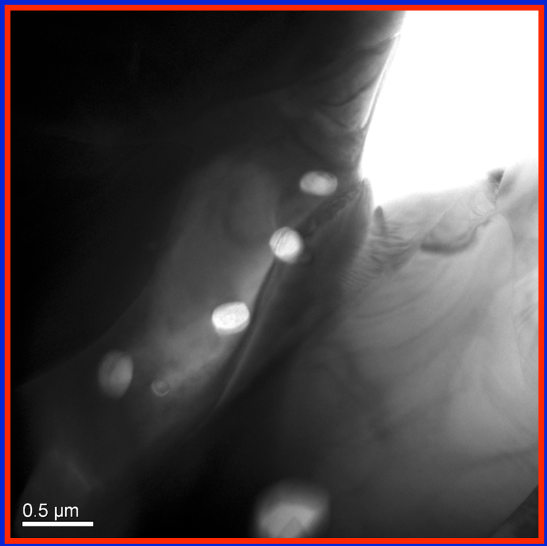
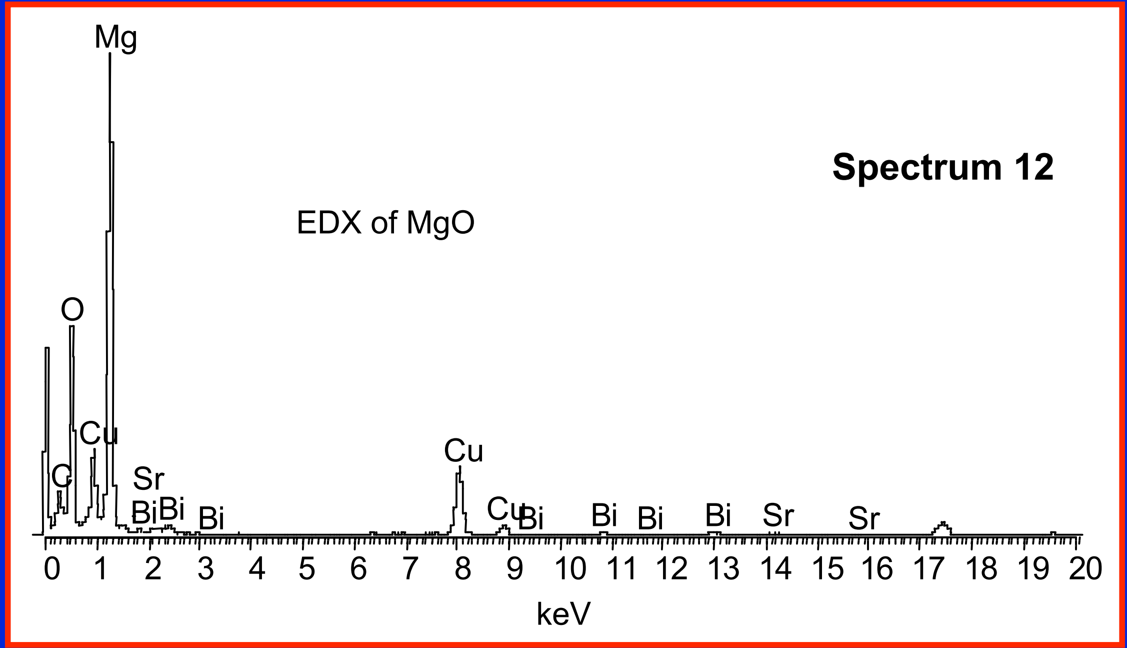
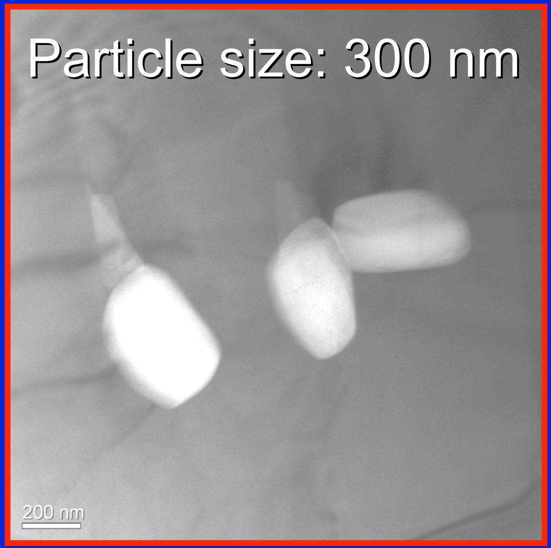
TEM of Bi-2212 Tape with MgO Nano-particles



(Mg,Cu)O nanoparticles in fully processed tapes

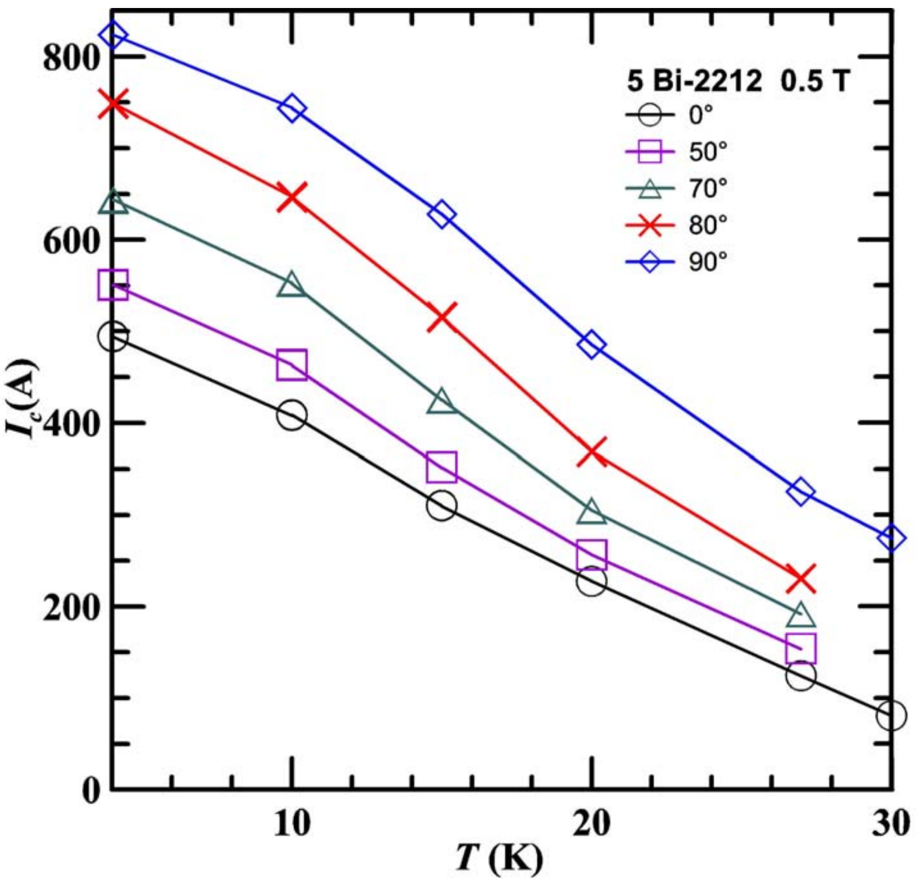


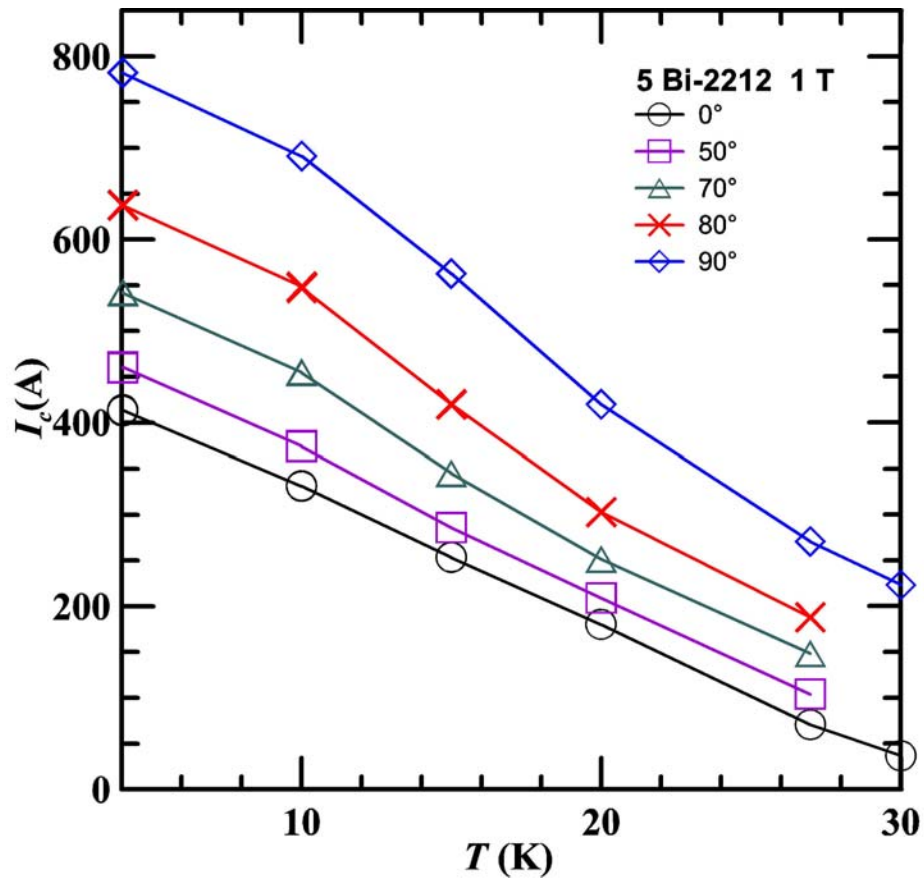


Summary

- National Laboratories have played a significant role in optimizing the Bi-2212 wires by
  - Introducing Al_2O_3 additions for secondary phase control and performance enhancement.
  - Microstructural analysis for compositional information and powder optimization.
  - Transport and magnetization measurements of the Bi-2212 conductor for temperature dependent performance benchmarks and conductor development.
  - Introducing nano-phase MgO additions for field performance (flux pinning) improvements.

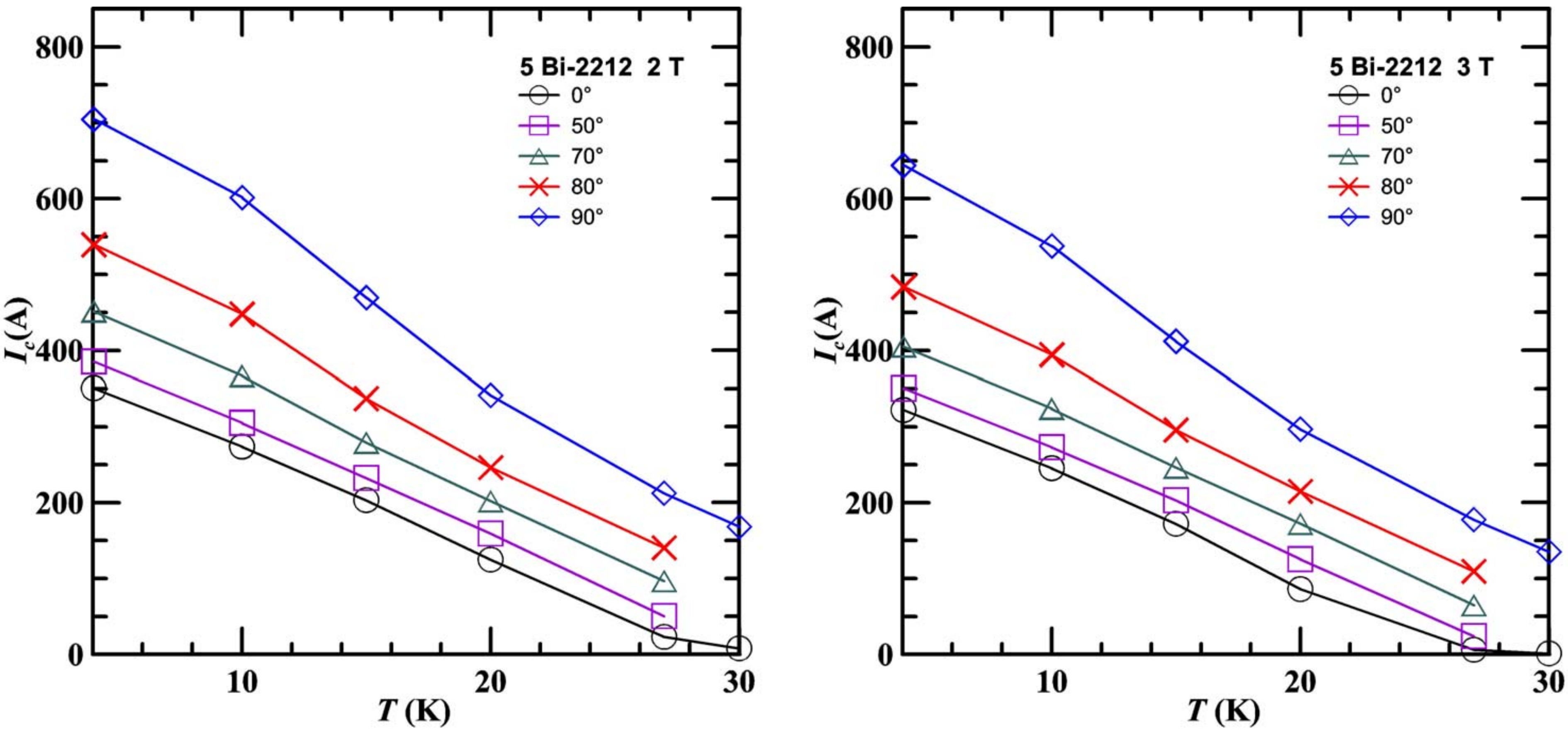
I_c versus T at various θ and given H





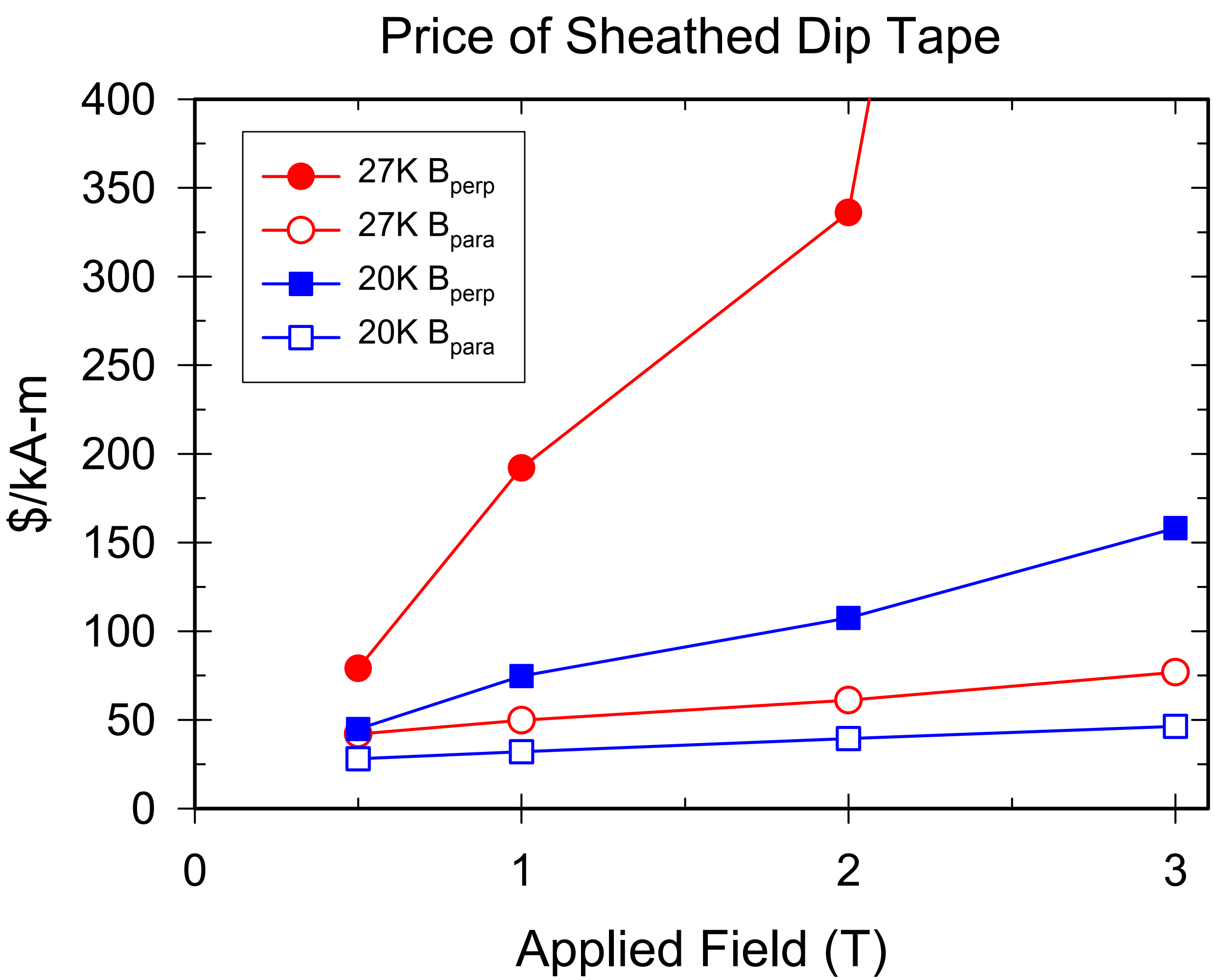
measurements by L. F. Goodrich

I_c versus T at various θ and given H



measurements by L. F. Goodrich

FY 2004 Results: Conductor Price



- Initial goal was \$10/kA-m at 20K, 0.5T
- System now demands 27K.
- Shifts in MRI market now demand 1.5T or greater.
- Imaging field of 1.5T requires 3T in the magnet winding.
- We estimate present price might be cut in half with volume and experience, but that is insufficient for MRI.

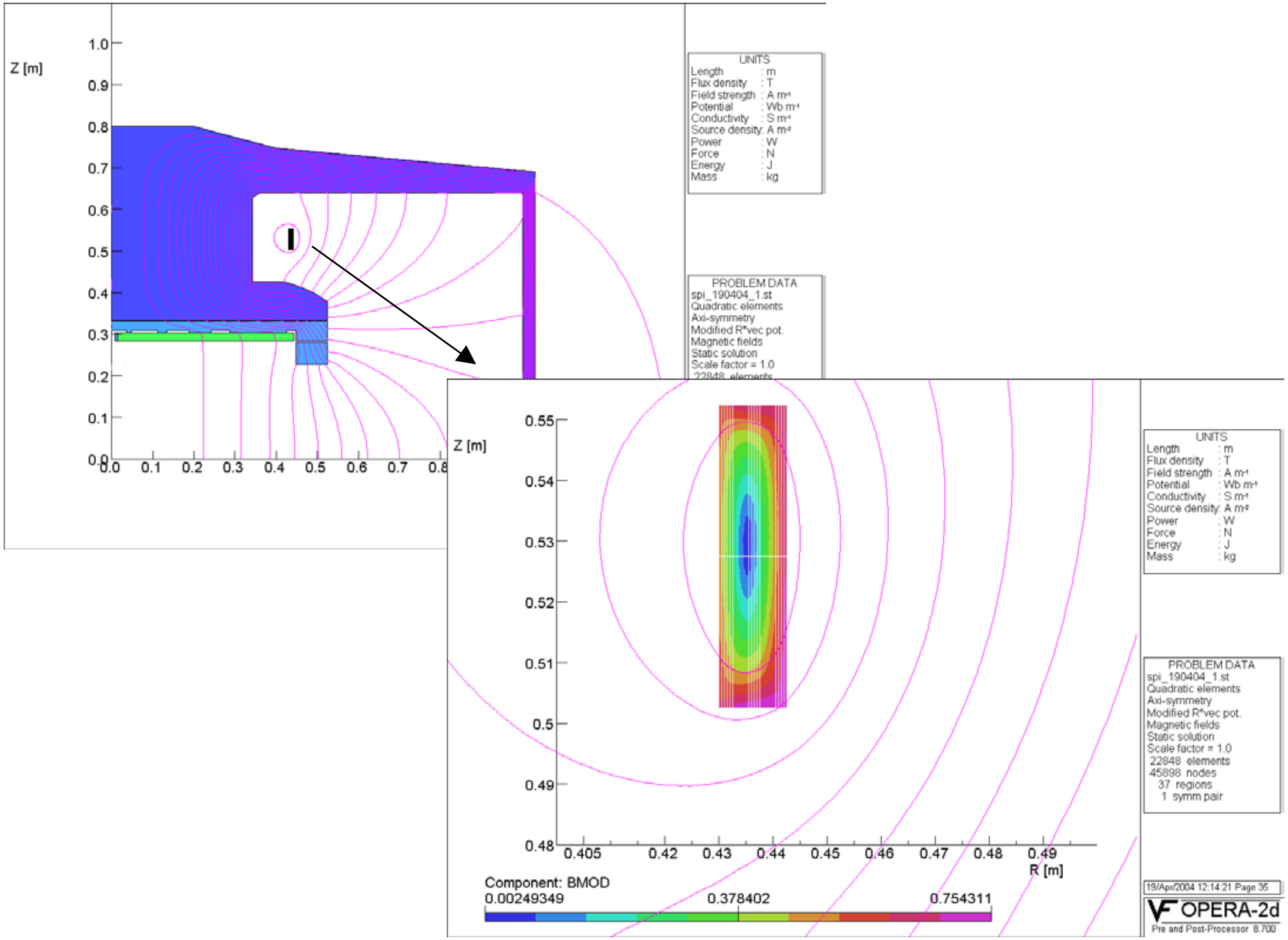
Optimisation of a MRI magnet design with HTS tape

Design assumptions based on resistive 0.2 T design with iron yoke :

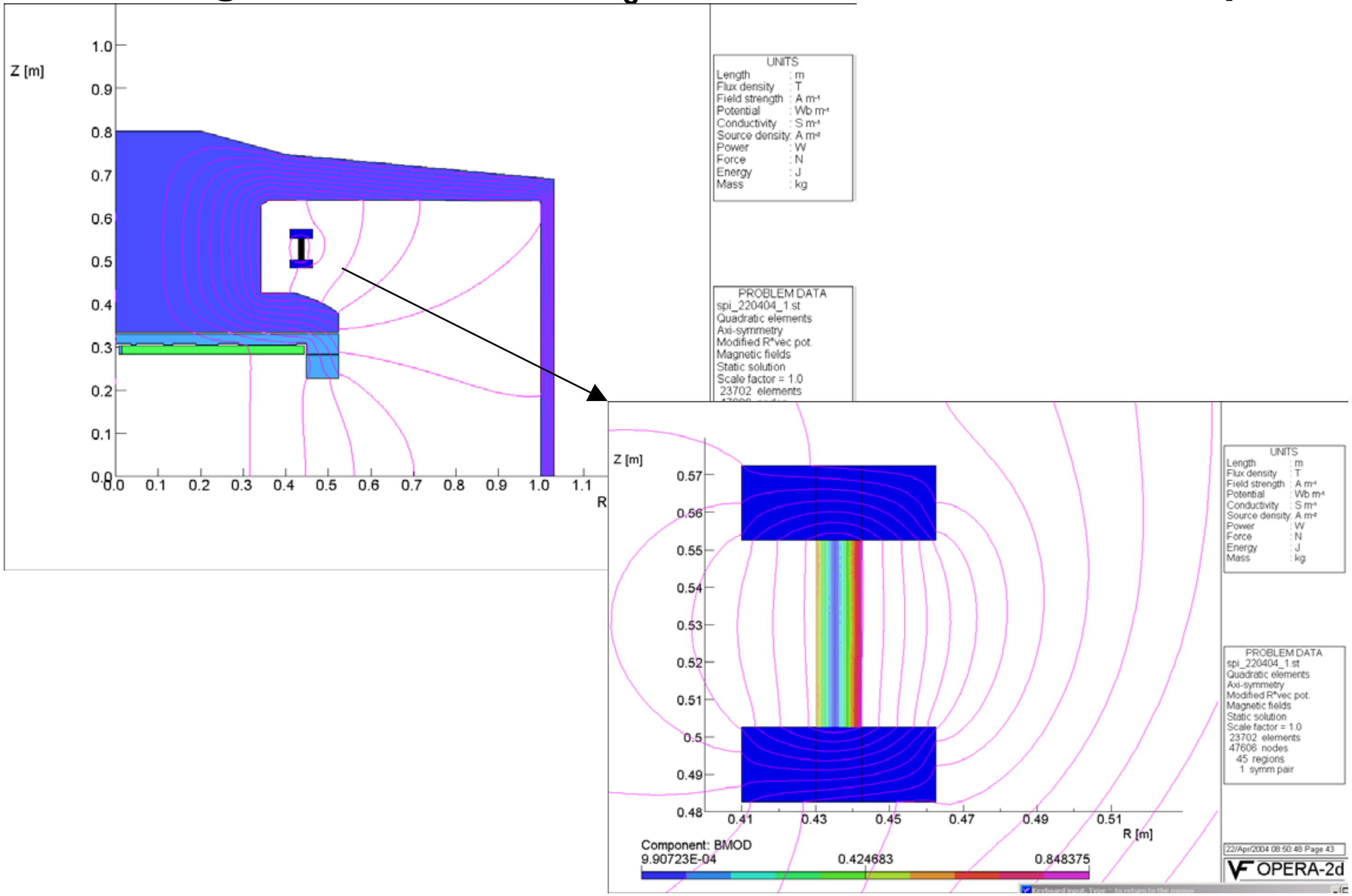
Central Field	0.2	T
Number of layers radially	25	
Number of layers, axially	2	
Total Ampere turns per coil	56120	A
Overall Tape width	25	mm
Grain angle spread	12	degrees
Overall Tape thickness	0.5	mm
Operating temperature	26.5	K
Current length per pair	308	kAm

- Total length of conductor will be determined by Current length / Ic :
- Operating temperature based on cryo system comprising a single refrigerator and a dual thermo syphon, delivering liquid Neon

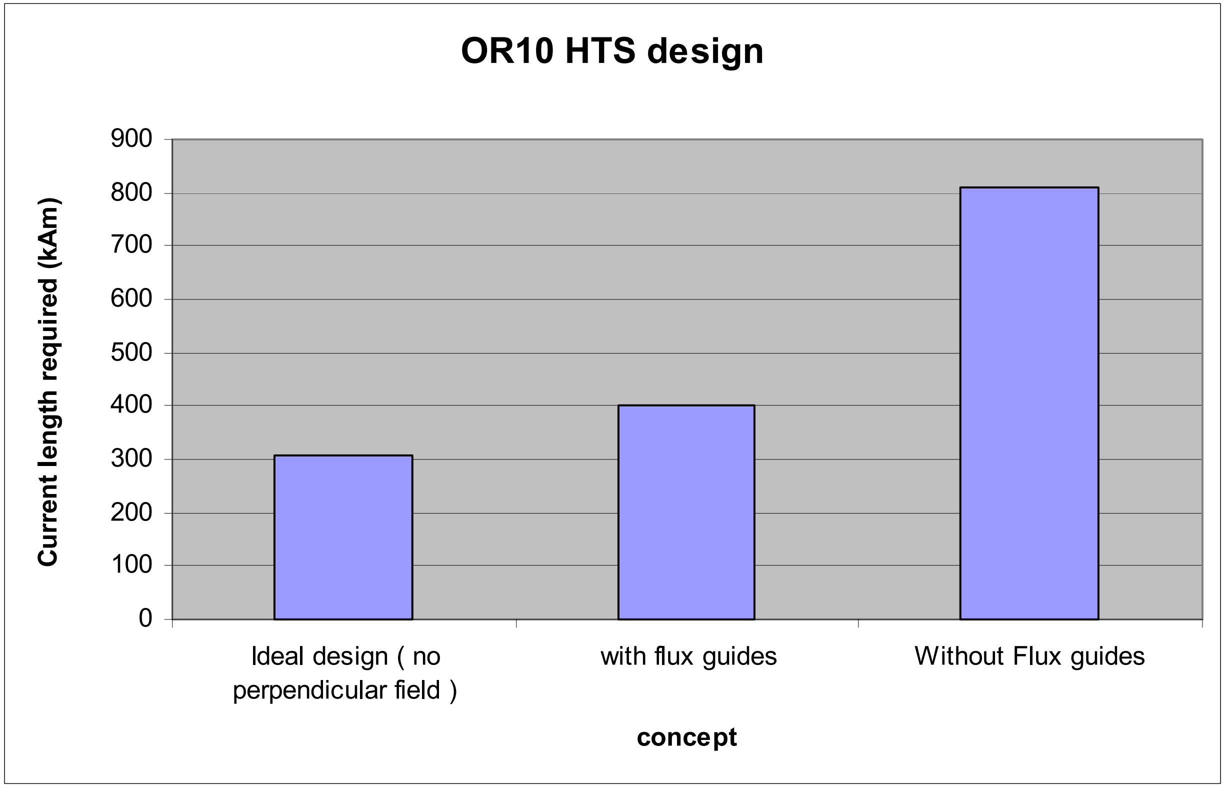
No Flux guides :
Radial magnetic fields limits I_c to about 36 % of maximum potential



Flux guides :
Radial magnetic fields limits I_c to about 75 % of maximum potential



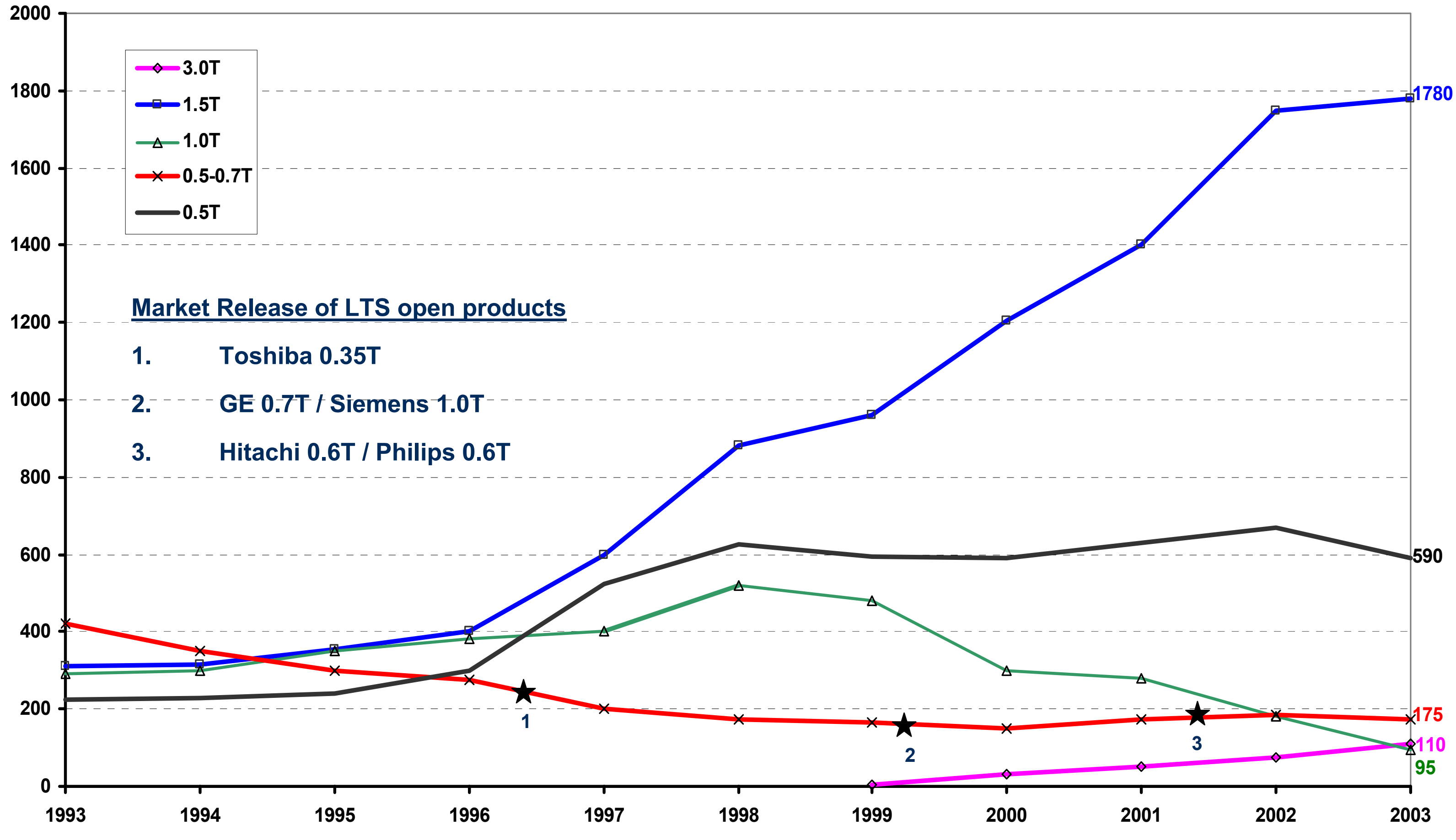
Comparison of concepts :



Conclusions:

- A 0.2 T magnet requires 400 kAm.
- A 0.6 T magnet requires >3000 kAm, based on an existing, similar, design.
- Designs must operate at >26 K for stable , cost effective cryogenic solution.
- Target conductor cost must be : 5 - 10 $/kAm
  (at 27 K, 0.6 T)
- Comparative LTS cost : 1 – 2 $/kAm
  (at 4.2 K, 3 T)
- Expected HTS tape cost : 75 $/kAm
  (at 27 K, 0.6 T)

Market Development – World Wide Units (Total 2002/03: 2750)



Market Development

- Systems below 0.3T employ permanent magnet material in Fe yoke
- Overriding issue is economy. Market sector is very price sensitive
- Low field market sector saturated
- Significant new products in the 0.5T to 1.0T open market sector have failed to stimulate demand
- Clear trend to move to 1.5T from open medium field systems

FY 2004 Summary

- Conductor is available to meet the technical requirements for this project.
- Based on performance and costs demonstrated in the last year, the economic targets cannot be met.
- The MRI market has changed substantially since this project was proposed in early 2001, and the demands of higher field and higher temperature have pushed the market requirements outside the useful window for BSCCO 2212.
- For these reasons the effort to use 2212 for MRI was ended.